EFFECT OF STRAIN AGEING IN WELDED AND NON WELDED LOW CARBON STEEL

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF

Bachelor of Technology

In

Metallurgical and Materials Engineering

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Department of Metallurgical and Materials Engineering

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Prof. A.K.PANDA

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NATIONAL INSTITUTE OF TECHNOLOGY

ROURKELA

CERTIFICATE

This is to certify that the work in this project report entitled "Effect Of Strain Ageing In Welded And Non Welded Low Carbon Steel" by ABHISHEK BANERJEE and SUMIT KUMAR DHAL has been carried out under my supervision in partial fulfillment of the requirements for the degree of Bachelor of Technology in Metallurgical and Materials engineering, National Institute of Technology, Rourkela is an authentic work carried out by them under my supervision and guidance.

To the best of my knowledge, this work has not been submitted to any other university/institute for the award of any degree or diploma.

Place: **Dr. Ashok Kumar Panda**

Date: **Professor**

Department of Metallurgical and Materials engineering

National Institute of Technology Rourkela, Orissa

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ACKNOWLEDGEMENT

It gives us immense pleasure to express our deep sense of gratitude to **Prof. Ashok Kumar Panda,** our guide and supervisor for his invaluable guidance, motivation and constant inspiration. It is not possible to acknowledge sufficiently his important contribution of talent and time given unselfishly in proceeding with this work. His constant voice of advice and constructive criticism has been our source of inspiration.

We are extremely thankful to **Prof B.B.Verma**, Head, Department of Metallurgical and Materials Engineering and **Prof M.Kumar** course coordinator for their help and advice during the course of this work.

We are also grateful to **Mr. S.Hembram** and **Mr. Uday sahu,** Metallurgical & Materials Engineering Department, for their help in carrying out this work.

We are greatly thankful to all the staff members of the department and all our well wishers, classmates and friends for their inspiration and help.

Place **Abhishek Banerjee**

Date **Sumit Kumar Dhal**

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ABSTRACT

Low carbon steels are susceptible to strain ageing as a result of which there is an increase in yield strength at the cost of ductility. These steels are used for structural applications, in which welding is used as a method of joining. There are certain regions away from the weldment which pass through the temperature range of 80 to 250^0c during cooling after welding. Since in many of the structures like ship building these steels are welded in deformed condition thus the above said regions are subjected to straining and ageing, thus leading to strain ageing.

In the present study an attempt has been made to study the effect of strain ageing in welded low carbon steel and the results are compared with those obtained after strain ageing of the same steel in the non welded condition. The parameters used were : (1) % The extent of pre-strain of pre-strain used was 6 ± 2 %.(2)The temperature of ageing used was 150 $\pm 30^0$c.(3)The time of ageing used was 4 ± 2 hrs. Using the method of Statistical Design Of Experiments the results were analysed to develop regression equations for welded as well as non welded steels. The equations developed are shown in eqn(1) and eqn(2) respectively.

For non welded: $\mathbf{\Delta Y = 24.04 - 2.18X1 + 4.9\ X2 + 1.4\ X3 - 0.03X1X2 - 0.018X1X3 + 35X2X3 - 0.28X1X2X3}$ (1)

For welded : $\mathbf{\Delta Y = 19.68 - 1.74X1 + 2.34\ X2 + 1.16\ X3 - 0.09X1X2 - 0.16X1X3 + .69X2X3 - 0.1875X1X2X3}$ (2)

In eqn (1) %pre-strain is assigned X_1, Temperature ^{0}c is assigned X_2 and time of ageing in hours is assigned X_3. It can be seen from eqn (1) that the b0 value is 24.04 MPa. This matches with the experimental value of ΔY of 23.5Mpa of the samples strain aged at 6% pre-strain, 150^0c ageing and 4 hours of ageing. This indicates that the equation developed is quite accurate within the boundary limits of the parameters. The coefficient of pre-strain (X_1) is – 2.18. The negative coefficient indicates that increasing pre-strain within the boundary limits used, decreases the ΔY value which can be seen from tables. The coefficient of temperature of ageing (X_2) is + 4.9 which is largely positive. This indicates the great influence of temperature of ageing. The coefficient of time of ageing (X_3) is +1.4. This value is less than coefficient of X_2 that is 4.9. This indicates that though time of ageing has got a positive of ΔY values, it has got less

pronounced effect than that of temperature of ageing.The interaction coefficient of X_1 X_2, X_2 X_3, X_1 X_3 and X_1 X_2 X_3 are small in comparison to main coefficients and hence are neglected.

In eqn (2) %pre-strain is assigned X_1, Temperature ^{0}c is assigned X_2 and time of ageing in hours is assigned X_3.It can be seen from eqn (2) that in the case of welded samples the b_0 value is 19.68 Mpa. This matches well with the ΔY value of 20.1 for the experiment carried out at 6% pre-strain , 150^{0}c of ageing and 4 hours of ageing. Here also the coefficient of pre-strain is negative, that is, -1.74. This can be explained as before. The coefficient of X_2 is +2.34 indicating that temperature has got a great influence in strain ageing. The coefficient of X_3 is +1.16 showing that time of ageing has got positive influence of strain ageing. This is less than 2.34 of X_2 indicating that time of ageing has got less positive influence than the temperature of ageing. The interaction coefficients are small and are neglected. Comparison of eqn (2) with eqn (1) indicates that each of the coefficients b_0, b_1, b_2 and b_3 are smaller in eqn (2) than those of eqn (1) indicating that ΔY values in the welded samples are less than in the non welded sample indicating that strain ageing is less pronounced in the welded sample.

Strain ageing response was found in welded low carbon steel samples. Pre-strain has been found to have a negative influence on both the welded and non welded samples. The temperature of strain ageing has got large positive influence on the extent of strain ageing. The time of strain ageing has positive influence on strain ageing though its impact is less than that of the temperature of strain ageing. The extent of strain ageing in the welded sample is less than that in the non-welded sample.

CHAPTER1

INTRODUCTION

1.Introduction

Strain ageing has been found to cause a deleterious effect in low carbon structural steels. A lot of studies have been made on the effect on the effect of different parameters on strain ageing characteristics of theses steels. Usually strain ageing occurs on low carbon steels in low temperature range approximately from 80^0c to approximately 250^0 c. These steels are used for structural applications where welding is used as a means of joining the members of the structure. Due to the welding the steel becomes molten at the joint. Far away from this fusion zone there is a region within the heat affected zone, in which the steel passes through the above temperature range. The members welded may be in a deformed condition for eg : plates bent before welding in the manufacture of ships. These deformed members passing through above temperature range may undergo strain ageing.

The purpose of this project is to investigate if any strain ageing phenomenon occurs in low carbon steels in the welded condition. There has been no published report regarding the effect of welding on strain ageing.

CHAPTER 2

LITERATURE REVIEW

2. Literature Review

2.1Strain Ageing [1,2]

Strain-ageing is a type of behavior, usually associated with the yield-point phenomenon,in which the strength of a metal is increased and the ductility is decreased on heating at a relatively low temperature after cold working[1]. Its mainly due to the interaction of point defects—specially the interstitial atoms and the dislocations during, or after the plastic deformation. If the change in the properties takes place after the plastic deformation (during the ageing period), then the process is called static strain-ageing or static strain-age hardening, though it is more commonly termed as strain-ageing. But if the change in the properties takes place as the plastic deformation progresses, then it is called dynamic strain-ageing.

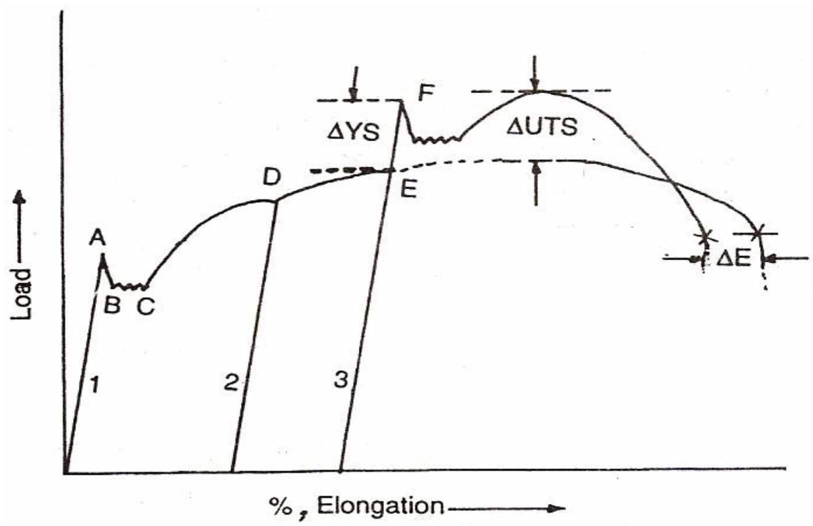

Fig- 2.1 Stress-Strain Curves for low carbon steels showing strain ageing

As shown in the above Fig2.1, A is upper yield point, B is lower yield point, BC is the Luders bands formation stage (this elongation is Luders elongation). From point C onwards, the specimen work-hardens and thus, the curve rises steadily and smoothly. If the plastic deformation of such a specimen of low carbon steel (in tensile test) is continued up to point D, and the specimen is then unloaded, and reloaded fairly soon, then it exhibits a curve of type (2), that is, on reloading, the specimen deforms elastically up to the unloading point D, and the yield point is absent at the beginning of the plastic flow (at D), because the newly created dislocations have not been locked by Cottrell atmospheres of carbon and nitrogen atoms. As enough time was not given (before reloading the specimen) and moreover the diffusion at room temperature is quite sluggish, thus, the diffusion and the resulting segregation of these interstitial solute atoms to the new dislocations have not occurred. If the specimen is strained up to a point, say E, and is then unloaded here. It is allowed to rest for several hours at room temperature, or a few seconds at 200°C. The specimen on reloading follows the curve 3, and the yield point is raised to point F, and the sharp yield point reappears. This process in which yield point reappears and is accompanied by the following effects is known as strain-ageing.

2.2 Changes Taking Place During Strain Ageing [2]

- The yield stress is raised during ageing by ΔYS.
- The ultimate tensile strength is raised by ΔUTS.
- The ductility decreases as indicated by the decrease in total elongation by ΔE.
- The yield point elongation (and thereby Luders band formation) takes place again. This elongation increases with ageing time.
- Ageing causes increased working-hardening-coefficient, or increased rate of work-hardening.
- Ageing causes low value of strain rate sensitivity, which is defined as the change in stress required to produce a certain change in the" strain rate at constant temperature.
- Strain-ageing is not susceptible to overageing. During (strain) ageing process (that is, during this time), a plastically deformed alloy reduces the energy of its strained lattice by the process of diffusion of interstitial solutes (carbon or nitrogen) to the dislocations.

2.3 Yield Point Phenomenon [3]

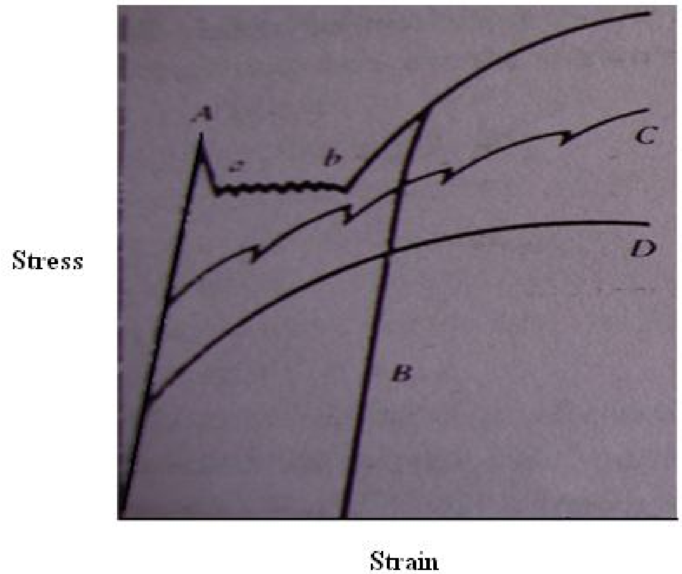

Fig-2.2 Stress-Strain Curves influenced by discontinuous loading

The carbon and nitrogen atoms possess a strong attraction for both edge and screw dislocations within the BCC iron lattice; accordingly, a solute “atmosphere” is formed around each dislocation core. Since these dislocations arc “pinned” by such solute atmospheres, dislocation motion is severely restricted until a sufficiently high stress (the upper yield point) is applied to enable dislocation to rip tree and move through the lattice.

Johnston and Gilman proposed that these unpinned dislocations multiply rapidly by multiple cross-slip mechanism. As result, the number of mobile dislocations increases sharply. yielding becomes easier and the load necessary for continued deformation decreases to the level associated with the lower yield point As additional regions(i.e., Luder bands) deform in this manner, the stress level remains relatively constant until essentially all dislocations have broken free from their respective solute atom clusters. At this point continued deformation Likes place by homogeneous plastic flow (fig. 2.2 curve a). Furthermore if the test was interrupted after completion of the luder strain region (ab) and the load removed and then immediately reapplied. The subsequent stress strain curve would not display any yield point (fig2.2 curve b). Although this explanation for yield-point phenomenon may be appropriate for iron single crystals containing small solute additions of interstitial carbon and nitrogen, it does not explain similar yield-point behavior in other material such as silicon ,germanium and lithium fluoride. Johnston and Hahn have proposed that yield-point behavior in these crystals is related to an initially low mobile dislocation density and a low dislocation-velocity stress sensitivity. regarding the latter, studies by stein and Gilman and Johnston and others demonstrated that the dislocation velocity depends on the resolved shear stress as given by eq. 2.1

$$\boldsymbol{\upsilon = (\tau/D)^m} \tag{2.1}$$

υ = dislocation velocity

τ = applied resolved shear stress

D,m are the material properties

Defining the plastic strain by : $\boldsymbol{\acute{\varepsilon}_p = Nb\upsilon}$ **(2.2)**

where $\acute{\varepsilon}_p$ = plastic strain rate

N = no of dislocations per unit area to move about and multiply

b = burgers vector

υ = dislocation velocity

Johnston argued that when the initial mobile dislocation density is low the plastic strain rate would be less than the rate of movement of the test machine crosshead and little overall plastic deformation would be detected at higher stress levels. The dislocations would be moving at higher velocity and also begin to multiply rapidly such that the total plastic strain rate would then exceed the rate of crosshead movement. To balance the two rates, the dislocation velocity would have to decrease. From Eq 2.2, this may be accomplished by a drop in stress, magnitude of which would depend on the stress-sensitivity parameter m. if m were very small (less than 20 as In the Case of covalent and ionic bonded materials as well as in some BCC metals), then a large drop in load would be required to reduce the dislocation velocity by the necessary amount. If m were large (greater than 100 to 200 as found for FCC metal crystals), only a small load drop would be required to effect a substantial change in dislocation velocity. The severity of the yield drop varies for a range of dislocation stress sensitivity values, the magnitude of the yield drop increasing with decreasing m. If there are many free dislocations present at the outset of the test, they may multiply more gradually at lower stress levels, precluding the occurrence of a sudden avalanche of dislocation generation at higher stress levels. The corresponding decrease in magnitude of yield drop with increasing initial mobile dislocation density is shown in From the above discussion, a yield point is pronounced in crystals that (1)contain few mobile dislocations at the beginning of the test. (2) Have the potential for rapid dislocation multiplication with increasing plastic strain, and (3) exhibit relatively low dislocation-velocity stress sensitivity. Since many ionic- and covalent bonded crystals possess these characteristics yield points are predicted and found experimentally in these materials. For the case of carbon- and nitrogen-locked dislocations in iron, dislocation mobility is essentially zero prior to the upper yield point where dislocations are finally able to tear away from interstitial atmospheres. it is theorized that the unpinning of some dislocations their rapid multiplication and weak velocity stress sensitivity (i.e low m value) all contribute to the development of a yield point in engineering iron alloys. By contrast, most fcc metals have an initially high mobile dislocation density and a very high dislocation-velocity stress sensitivity, thereby making a yield drop an unlikely event in most of these materials. The serrated character of type iii stress—strain behavior in plain carbon steel alloys can also be explained in terms of dislocation—solute atom interactions. After dislocations have ripped away from their solute atmospheres, homogeneous plastic flow occurs unless the tensile test was conducted at moderately elevated temperatures (e.g.. approximately 200°c); for this condition. Enhanced diffusion would enable carbon and/or nitrogen atmospheres to reform, thereby repining dislocations. The applied stress would then have to increase further to enable dislocations to again break tree iron their solute clusters. so long as the diffusion rate for the solute atoms is equal to or slightly greater than the rate of plastic deformation dislocations will alternately break free from solute atmospheres and then be repined, this produces the serrated stress—strain curve, if the test temperature was much higher. Homogeneous dislocation flow would take place since solute atmosphere formation would no longer be favored, accordingly the stress-strain curve would be smooth

2.4Metallurgical Factors For Strain Ageing [4]

1. The presence of interstitial elements in steel is the most important factor. These alloying elements in the steel are dispersed into their characteristic micro structural constituents, predominantly iron and iron carbide. Carbon and Nitrogen are the most important elements to cause strain ageing
2. The effect of temperature is important for the "aging" phenomenon. The temperature range of 80 to 250^0c for periods of 1-5 hr is most critical after cold deformation (alone) is done to steels. When dislocations break away for their pinning interstitial atoms and begin the movement causing slip they begin to intersect with each other. A complex series of interactions between the dislocations occurs resulting in the formation of jogs and there by movement of dislocations stops, and when heating follows cold deformation, the loss in ductility and toughness is greater.
3. Elements that show the phenomenon of strain ageing must have low initial mobile dislocation density
4. There may be certain compounds (carbonitrides), that can form that also restrict the motion of the dislocations and raises the strength of the steel.

2.5Control Of Strain Aging [4,5]

There are some well-established methods for control of strain aging but only few are adopted by the industries because most of the suggested measures are impractical.

1. The first approach is to eliminate the presence of the interstitial elements, particularly the carbon and nitrogen that can cause this phenomenon. , this has proven to be either difficult or expensive to do on a regular basis.
2. A 2% "skin pass rolling is given to eliminate stretcher strains.
3. This high activation energy is believed to be the result of interactions between interstitial solutes and strain fields of the coherent precipitates which strengthen HSLA steels. Consequently, strain aging in HSLA steels is considerably slower than in plain carbon steel.

4. Another approach is to deoxidize the steel with aluminum as well as silicon. Aluminum-silicon deoxidation is intended to not only remove dissolved oxygen from the steel as oxides but also to combine aluminum with nitrogen to form aluminum nitrides that help to control grain size during and after heat treatment. This should remove free nitrogen from the steel in the form of nitrides and eliminate one cause of strain aging.
5. A procedure that is sometimes effective in reducing the toughness loss in strain aging is to apply a heat treatment after straining to cause “overaging” of the steel. This process is virtually the same as used to stress relieve weldments and requires heating the strained material to temperatures in the 1000^{o}F to 1150^{o}F range.

2.6work Done In This Field(Literature Survey)

Strain ageing is observed in low carbon steel and result in an increase in strength and decrease in ductility. It is generally accepted that these effects are due to uncombined interstitial atoms such a carbon or nitrogen migrated to dislocation and locking them further as little as 0.00012 to 0.001 free carbon or nitrogen is sufficient to cause strain ageing.

F vodopivec[6] studied “Strain Ageing Of Structural Steels” - a normalised steel with the microstructure of polygonal ferrite and pearlite. linear intercept grain size of 16.6 μm and the yield stress of 377 MPa, a steel with a microstructure of quenched and tempered ferrite and pearlite, linear intercept grain size of4.7 μm and the yield stress of 522 MPa and a steel with a microstructure of tempered martensite, linear intercept grain size of 2.5 em and the yield stress of 737 MPa. He showed that strain ageing affects the properties of all tested steels in spite of their different microstructure. Tensile properties are affected to a different measure: yield stress and tensile strength are strongly increased, while, reduction of area is slightly and uniform elongation is strongly decreased. The increase of yield stress is greater for lower as delivered yield stress, while the effect on uniform elongation is smaller with higher yield stress steel. The change in tensile properties is due mostly to the effect of strain hardening after 10% of plastic cold deformation. After 10% plastic deformation and after ageing at 250 °C the Charpy notch toughness transition temperature is not changed. in comparison to that for the normalised steel.

This temperature is increased only as the effect of synergy of deformation and ageing producing an interplane segregation of carbon atoms which decreases the ferrite cleavage strength.

J**. Belotteau, C. Berdin, S.Forest, A. Parrot, C. Prioul**[7] studied "mechanical behavior modeling in the presence of strain aging" This study has shown that a simplified softening behaviour law allows to simulate the main features associated to static strain aging. Nevertheless all the characteristics of the stress – strain curve plateau cannot be deduced only from the local intrinsic behaviour. The Lüders plateau is not only sensitive to the mesh, but also to the boundary conditions and the way the Lüders band is being initiated. Introducing an artificial defect exerts a large influence on the stress plateau level. From the tentative correlation between the local and global behaviour it can be concluded that he maximum stress of the local law can be approximately related to the measured macroscopic peak stress. The length of the plateau corresponds roughly to the plastic strain for which global and local behaviour coincide. The simplified law used in this study well simulates Lüders behaviour but remains a phenomenological law. It does not take into account the physical origin of strain aging, is not temperature and strain rate dependant and does not simulate dynamic strain aging. So, to further understand the influence of static and dynamic strain aging on fracture toughness, it will be necessary to identify and apply the McCormick - Zhang model to fracture geometry specimen, to further predict the loss of fracture toughness in the presence of strain aging.

A. K. De, S. Vandeputte and B. C. De Coomans[8] studied "Competition between grain boundary segregation and Cottrell atmosphere formation during static strain aging in ultra low carbon bake hardening steels". They concluded that Carbon segregation during CA lowers the solute carbon at the start of strain aging. It is reduced for longer soaking times because the grain size increases, and for higher cooling rates limit the segregation time. Experimental work on an ULC grade with 450 ppm phosphorus with internal friction was compared with computer simulations based on finite difference modeling of segregation. For the computer model, a spherical grain approximation was used. Carbon segregation to dislocations during strain aging was modelled through the application of diffusion dynamics based on a Monte-Carlo algorithm. The model takes into account the dislocation saturation effects and carbon segregation to the grain boundaries. The degree of atmosphere formation evolved by the model corresponds to the experimental strain aging results of an ultra low carbon bake hardening steel carried out at temperatures 50–170 °C. It was assumed that the increase in the yield stress due to aging varies linearly with the dislocation saturation i.e., the reduction in free dislocation density by carbon atoms. The temperature dependence of the aging process was successfully predicted. It was also clear that variation in the dislocation density over a large range, induced by different pre-strains, does not influence the degree of dislocation saturation provided the minimum amount of solute carbon needed to complete atmosphere formation is available in the matrix. Theoretical prediction of dislocation saturation as a function of varying dislocation density was in good agreement to the experimentally observed aging results. These work also revealed that during conventional bake hardening cycles, carbon segregation to grain boundaries is negligible, since the kinetics of this process is much slower than for segregation to dislocations.

l. a. erasmus and l. n. pussegoda[(9)] studied "The Strain Aging Characteristics of Reinforcing Steel with a Range of Vanadium Contents". Their findings revealed that **t**he strain aging characteristics of reinforcing steel made with vanadium ranging between zero and 0.1 % and with two aluminium levels for the as hot rolled condition. They showed that that vanadium contents of 0.04 to 0.06 % (a V/N ratio of 7 to 9) will result in the combination of almost all the active nitrogen as vanadium nitride and suppresses natural strain aging. Vanadium in excess of this level results in the precipitation of vanadium carbide and the consequential precipitation hardening gives an increase in the yield strength, tensile strength, and impact transition temperature without imparting further beneficial effect with regard to strain aging. The mechanical properties have been shown to be generally unaffected by the two different aluminium levels, and no grain refinement resulted from either the vanadium or aluminium additions. This absence of grain refinement and the precipitation hardening results in an increase in the impact transition temperature with increasing vanadium content, although this increase is initially slow whilst the active nitrogen content is being reduced.

V. S. Ananthan and E O. Hall[(10)] studied "macroscopic aspects of luders band deformation in mild steel". They concluded that the nature of the band front will depend on the grain size and the geometry of the cross-section. The generation of the single bands depends on the *l/ t* ratio of the specimens and test speed, whereas the diffuse nature of the Luders bands mainly depends on the grain size. Specimens with flatter cross-section (rectangular, square, etc.) tended to yield multiple and/or complex bands compared with the specimens of circular crosssections, and specimens of coarser grain size (>0.15 ram) generally produced diffuse bands in this study. The grip effects and the bending moment associated with the shear kink influence the deviation of the orientation angle of the band front and the direction of maximum kink angle. The direction of maximum kink angle did not lie in the direction of the greatest slope in the shear plane. The angle of the band front with the specimen axis (average value of 51 ± l ° for all the specimens) observed in this study is in agreement with the results reported earlier. However, this angle deviated away from 45 ° in coarser grained material in all the specimens except the square ones. The Luders strains calculated based on a model of "shear-flow" compares well with the experimental values of the strain. Further modifications to this model should include factors such as grip effects, specimen geometry, bending moment associated with the kink, test speed, etc. The Hall-Patch relation was found valid for all the specimen shapes. The Luders strain may also be related in a similar fashion within the range of grain sizes studied. The Luders deformation will mainly consist of shear in finer grained specimens while, as the bands become diffuse in coarser grained specimens, the shear contribution to the total deformation is lowered. Hence, the dependency of the luders strain on grain size is because of its shear component dependency on grain size, whereas the grain size may have little effect on its flow component.

Süleyman Gündüz , Atilla Tosun[11] studied ”Influence of straining and ageing on the room temperature mechanical properties of dual phase steel” ,in his work, changes in mechanical properties in dual phase steel containing 20% martensite volume fractions were observed at various ageing temperatures Static strain ageing in microalloyed dual phase steel was studied by the measurement of the changes in yield stress due to ageing in specimen pre-strained in the range of 2 and 4%.They concluded that the smooth stress–strain curves in dual phase steel are a result of the motion of free dislocation in the ferrite. These dislocations were produced by the volume change that occurs when the austenite regions transform to martensite. The ageing treatment at 100 ^{0}C caused an increase in YS. This is due to the formation of solute atom atmospheres around dislocations. Further increase in ageing temperature to 200^{0}C caused a reduction in the yield strength due to overageing resulted from tempering that starts in martensite. Variation of pre-strain in the range 2 and 4% has negative effect on the changes in ΔY in subsequent ageing, although the dislocation density would probably be increased by increasing the pre-strain from 2 to 4%. This indicated that a change in ΔY values is insensitive to dislocation density.

CHAPTER 3

EXPERIMENTAL PROCEDURE

3.Experimental Procedure

Low carbon steel sheet used for the experiment were of the following composition:

Element	C	Mn	Si	P	S	Al
%	0.06	0.26	0.031	0.019	0.012	0.055

Rectangular strips of dimension 210mm X 25mm were cut out of the steel sheet. Some 10 strips were held together and their edges were tagged by welding. These strips were machined by universal milling machine in order to obtain such sheet tensile specimens. After the bunch was machined edges were round in order to separate the specimens made. Some tensile samples were preserved for strain ageing as such, the other half of the samples were cut transversely in the middle and then were welded by gas welding.

The dimension of the specimen is shown in fig:

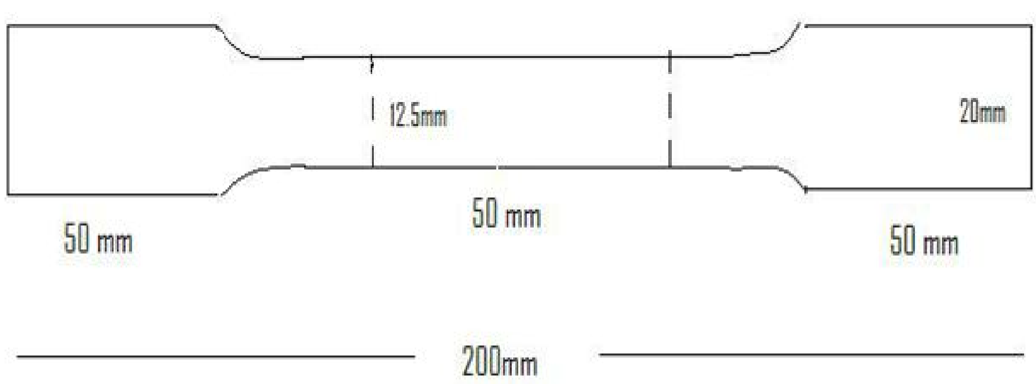

Fig 3.Dimensions of the specimen used in the experiment

The factors affecting strain ageing are :

(1) Extent of pre-strain
(2) Temperature of ageing
(3) Time of ageing

The extent of pre-strain of pre-strain used was 6 ± 2 %

The temperature of ageing used was 150 ±30^{0}c

The time of ageing used was 4 ± 2 hrs

The following planning was made in order to carry out the strain ageing

Table 1. Schedule Of The Strain Ageing Experiment

SL NO	PRE-STRAIN[%] (X1)	TEMPERATURE[^{0}C] (X2)	TIME [HRS] (X3)
1	8	180	6
2	4	180	6
3	8	120	6
4	4	120	6
5	8	180	2
6	4	180	2
7	8	120	2
8	4	120	2
9	6	150	4

The tensile test was carried out in INSTRON 1195 machine. The following procedure was used for pre-straining: First the dummy samples were tested. The total strain was found out from strip-chart recorder. The assigned values of 4% , 8% and 6% of pre-strain were thus calculated out. A line was drawn parallel to the linear portion of the tensile curve of the dummy sample. Next another parallel line was drawn at 4% pre-strain. For pre-straining, a sample was held in the machine and tension test was started. Before starting the tension test care was taken to see that the pen stylus of the strip chart recorder coincided with the origin of the first parallel line which was drawn from the X- axis. Simultaneous with loading the pen stylus moved. The moment it touched the second parallel line drawn at 4% pre-strain,loading was stopped and sample was unloaded. Similar procedure was adopted for 8% pre-strain and 6% pre-strain.

After all the specimens were pre-trained, they were aged in a moisture oven using the temperature range of 150 ± 30^{0}c. Samples were dipped in oil bath. There was provision of monitoring of temperature by mercury thermometer, whose tip was dipped in oil bath in which the specimen was submerged. The specimens were taken out after the elapse of the prescheduled time of 4 ± 2 hrs.The welded samples were pre-strained and, strain aged following the above procedure and following the schedule mentioned in Table 1.

After all the samples were strain aged , tension test was carried out. Initially the 4% pre-strain sample was chosen. Again before the starting of the test, the pen stylus of the strip chart recorder was made to coincide at the origin of the parallel line drawn at 4% pre-strain. It was observed that the yield point reappeared in the strain aged at a higher stress value than that appeared before ageing. the difference between second generation lower yield stress and the highest stress at the pre-starin is referred to as Δy. Similarly tension test was carried out for all strain aged samples for different values of pre –strain subjected to various temperatures and various time periods of ageing. This was carried out for non welded samples as well as welded samples.

The results of the experiments were analysed by the use of Statistical Design Of Experiments and a Regression equation was developed which is the form. The regression equation to be developed is of the form:

$$\Delta \mathbf{Y} = \mathbf{b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 + b_{123}X_1X_2X_3} \qquad (1)$$

Where: X_1[PS] = 6 ± 2 %

X_2[Temp ^{0}c] = 150 ± 30^{0}c

X_3[Time in hrs] = 4 ± 2 hrs

Machine details:

Fig-4.INSTRON 1195 used in the experiment

Load Cells	5 N - 100 KN
Crosshead Speed Range	0.5 - 500 mm/min
Return Speed	500 mm/min
Crosshead Speed Accuracy	±0.1% of Set Speed
Space Between Columns	560 mm
Testing Type	Tension and Compression
Drive Unit	Lead Screws
Main Application	Tensile Compression & 3 point bend tests

CHAPTER 4

RESULTS AND DISCUSSION

4.Results and Discussions

Table 2.Result Of The Strain Ageing In Non Welded Sample

SL NO	PRE-STRAIN[%] (X1)	TEMPERATURE [^{0}C] (X2)	TIME [HRS] (X3)	ΔY (MPa)	Mean ΔY (MPa)
1	8	180	6	30.5	30.3
				30.1	
2	4	180	6	35.3	35.6
				35.9	
3	8	120	6	20.1	20.4
				20.7	
4	4	120	6	24.8	24.5
				24.2	
5	8	180	2	27.4	27.7
				28.0	
6	4	180	2	31.6	31.2
				30.8	
7	8	120	2	18.5	18.1
				17.7	
8	4	120	2	22.2	22.6
				23.0	
9	6	150	4	23.8	23.5
				23.2	

Table 3.Result Of The Strain Ageing In Welded Sample

SL NO	PRE-STRAIN [%] (X1)	TEMPERATURE [^{0}C] (X2)	TIME [HRS] (X3)	ΔY (MPa)	Mean ΔY (MPa)
1	8	180	6	20.4 21.0	20.7
2	4	180	6	24.6 24.0	24.3
3	8	120	6	16.9 17.5	17.2
4	4	120	6	21.4 21.0	21.2
5	8	180	2	20.1 19.3	19.7
6	4	180	2	22.7 24.1	23.4
7	8	120	2	14.5 13.9	14.2
8	4	120	2	16.3 17.3	16.8
9	6	150	4	20.5 19.7	20.1

ΔY values were calculated for all the samples. The ΔY values are tabulated against different combinations of parameters of strain ageing, that is, % pre-strain, temperature of ageing and time of ageing. These results are shown in Table 2 for non-welded samples and Table 3 for welded samples.

By analysing the results of ΔY values for the non-welded samples (from Table 2) using the Statistical Design Of Experiments, the following eq^n was developed:

$$\mathbf{\Delta Y = 24.04 - 2.18X1 + 4.9\ X2 + 1.4\ X3 - 0.03X1X2 - 0.018X1X3 + 35X2X3 - 0.28X1X2X3} \qquad (2)$$

In eq^n (2) %pre-strain is assigned X_1, Temperature ^0c is assigned X_2 and time of ageing in hours is assigned X_3. It can be seen from eq^n (2) that the b0 value is 24.04 MPa. This matches with the experimental value of ΔY of 23.5Mpa of the samples strain aged at 6% pre-strain, 150^0c ageing and 4 hours of ageing. This indicates that the equation developed is quite accurate within the boundary limits of the parameters. The coefficient of pre-strain (X_1) is – 2.18. The negative coefficient indicates that increasing pre-strain within the boundary limits used, decreases the ΔY value which can be seen from tables. The coefficient of temperature of ageing (X_2) is + 4.9 which is largely positive. This indicates the great influence of temperature of ageing. The coefficient of time of ageing (X_3) is +1.4. This value is less than coefficient of X_2 that is 4.9. This indicates that though time of ageing has got a positive of ΔY values, it has got less pronounced effect than that of temperature of ageing. The interaction coefficient of X_1 X_2, X_2 X_3, X_1 X_3 and X_1 X_2 X_3 are small in comparison to main coefficients and hence are neglected.

Similarly by analysing the results of ΔY values for the welded samples (from Table 3) using the Statistical Design Of Experiments, the following eqn was developed:

$$\Delta Y = 19.68 - 1.74X1 + 2.34\ X2 + 1.16\ X3 - 0.09X1X2 - 0.16X1X3 + .69X2X3 - 0.1875X1X2X3 \quad (3)$$

In eq^n (3) %pre-strain is assigned X_1, Temperature ^0c is assigned X_2 and time of ageing in hours is assigned X_3.It can be seen from eq^n (3) that in the case of welded samples the b_0 value is 19.68 Mpa. This matches well with the ΔY value of 20.1 for the experiment carried out at 6% pre-strain , 150^0c of ageing and 4 hours of ageing. Here also the coefficient of pre-strain is negative, that is, -1.74. This can be explained as before. The coefficient of X_2 is +2.34 indicating that temperature has got a great influence in strain ageing. The coefficient of X_3 is +1.16 showing that time of ageing has got positive influence of strain ageing. This is less than 2.34 of X_2 indicating that time of ageing has got less positive influence than the temperature of ageing. The interaction coefficients are small and are neglected. Comparison of eq^n (3) with eq^n (2) indicates that each of the coefficients b_0, b_1, b_2 and b_3 are smaller in eq^n (3) than those of eq^n (2) indicating that ΔY values in the welded samples are less than those obtained in the non welded sample indicating that strain ageing is less pronounced in the welded sample.

The welded samples do have as a result of welding and transformation a high dislocation density. The fundamental requirement for yield point phenomenon is low initial dislocation density. Since the dislocation density in welded sample is large, there will be large number of mobile dislocation to be locked, thus the ΔY value is less.

CHAPTER 5

CONCLUSION

5. Conclusion

1. Strain ageing response was found in welded low carbon steel samples.
2. Pre-strain has been found to have a negative influence on both the welded and non welded samples.
3. The temperature of strain ageing has got large positive influence on the extent of strain ageing.
4. The time of strain ageing has positive influence on strain ageing though its impact is less than that of the temperature of strain ageing.
5. The extent of strain ageing in the welded sample is less than that in the non-welded sample.

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